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04 Locomotion & Movement (Skeletal System)

1. Introduction :

- **Skeletal system** consists of a **framework of bones** and a **few cartilages**.
- This system has a significant role in movement shown by the body.

SWIMMING

JUMPING

WALKING

RUNNING

- Imagine **chewing** food **without jaw** bones and **walking** around **without the limb bones**.
- Bone and cartilage are specialised connective tissues.

Bone	Cartilage
Very hard matrix.	Slightly pliable matrix
Calcium salts present.	Chondroitin salts present
Bone marrow is present that produces blood corpuscles.	Such structure is absent.
Growth in bone is bi-directional.	Growth is cartilage is unidirectional.

- In human beings, this system is made up of 206 bones and a few cartilages. It is grouped into two principal divisions – the axial and the appendicular skeleton.

Human Skeletal System

- Bones-206
  - Axial Skeleton
  - Appendicular Skeleton
- Cartilages

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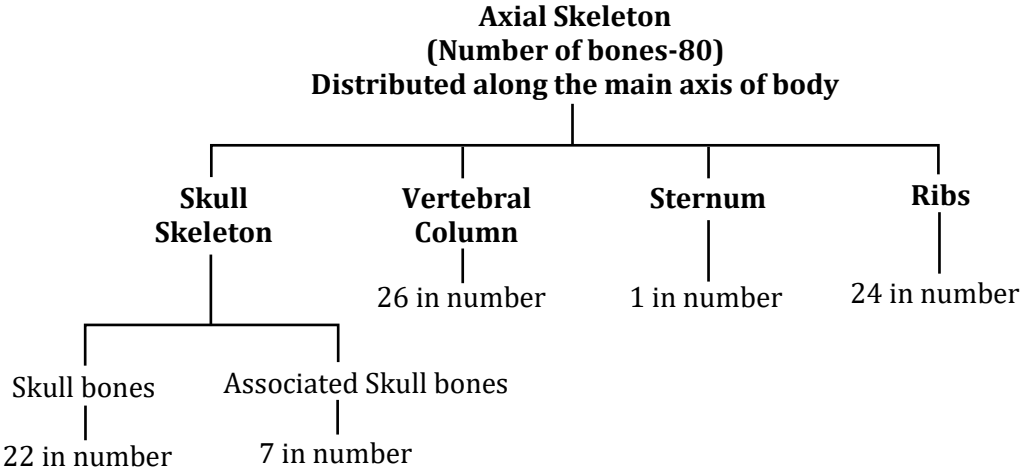
2. Axial Skeleton :

- Axial skeleton comprises 80 bones distributed along the main axis of the body. The skull, vertebral column, sternum and ribs constitute axial skeleton.



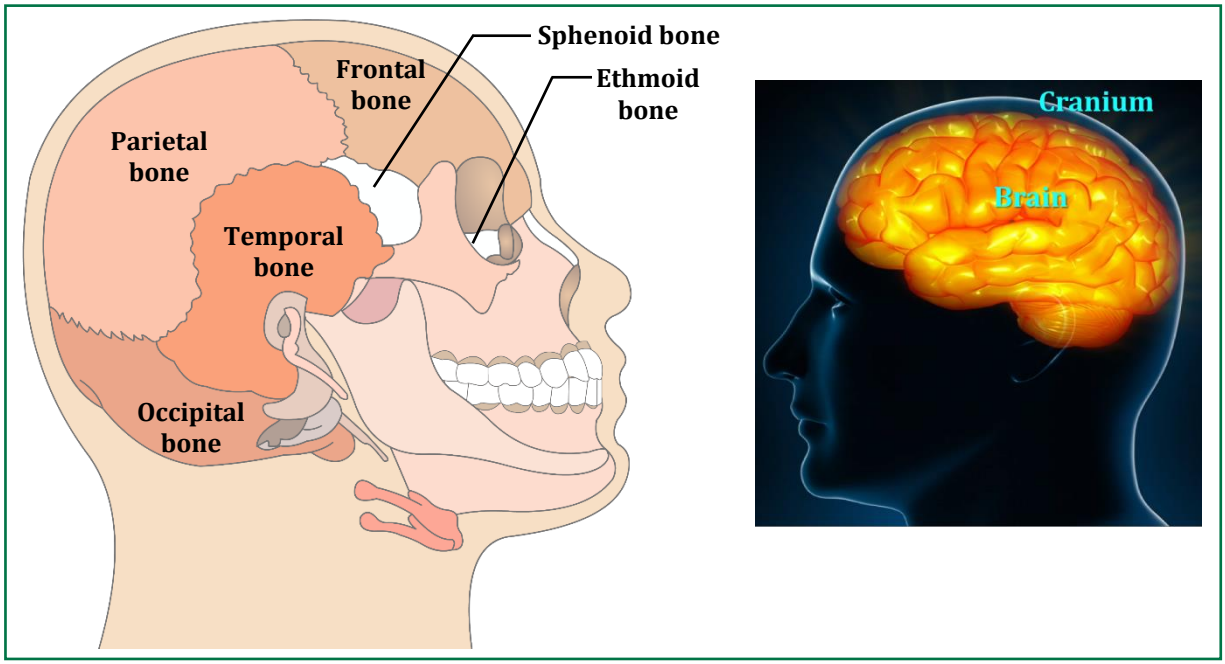
(A) Skull :

- The Skull is composed of **two sets of bones** – **cranial** and **facial**, that totals to 22 bones.

Cranial Bones :

Cranial bones are 8 in number **(frontal-1, parietal-2, temporal-2, occipital-1, ethmoid-1 and sphenoid-1).**

Functions of cranial bones : They form the hard protective outer covering, cranium for the brain.



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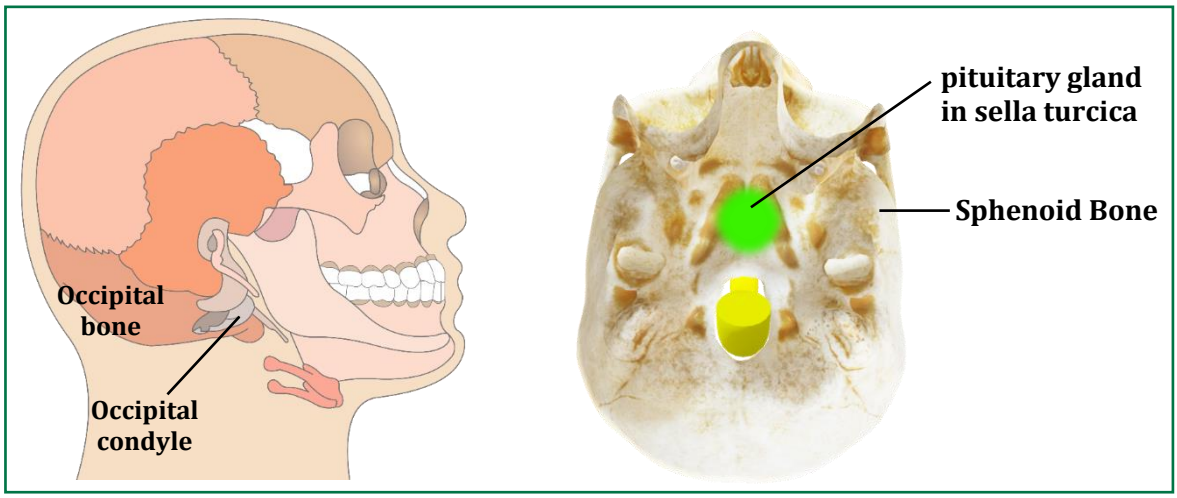
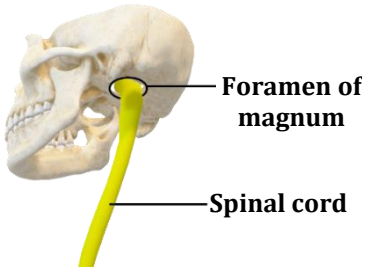
Articulation of Skull With Vertebral Column :

- The skull region articulates with the superior region of the vertebral column with the help of two occipital condyles (dicondylic skull).
- Occipital bone consist of two projections called **Occipital condyles** therefore our skull is called **dicondylic skull**.

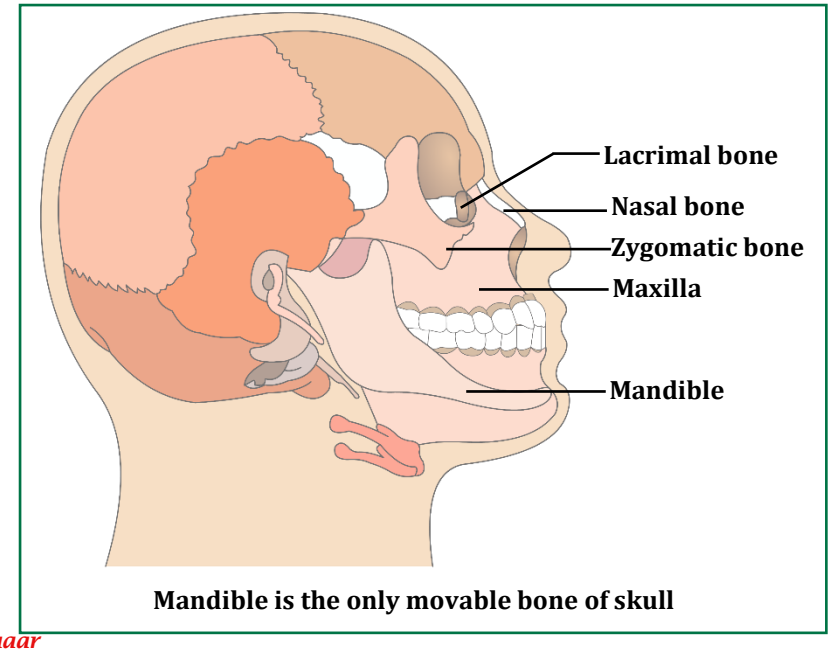


- Cavity of sphenoid bone is called **sella turcica** in which pituitary gland is present.
- At the base of skull an opening is present called **foramen of magnum (Largest Foramen of Skull)** through which **spinal cord** comes out.



Facial Bones :

- The facial region is made up of 14 skeletal elements (Inferior turbinals-2, Maxilla-2, Malar (Zygomatic)-2, Nasal-2, Palatine-2, Lacrimal-2, Vomer-1, Mandible-1) which form the front part of the skull.



Mandible is the only movable bone of skull

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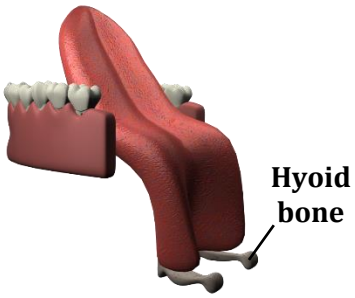
Hyoid Bone :



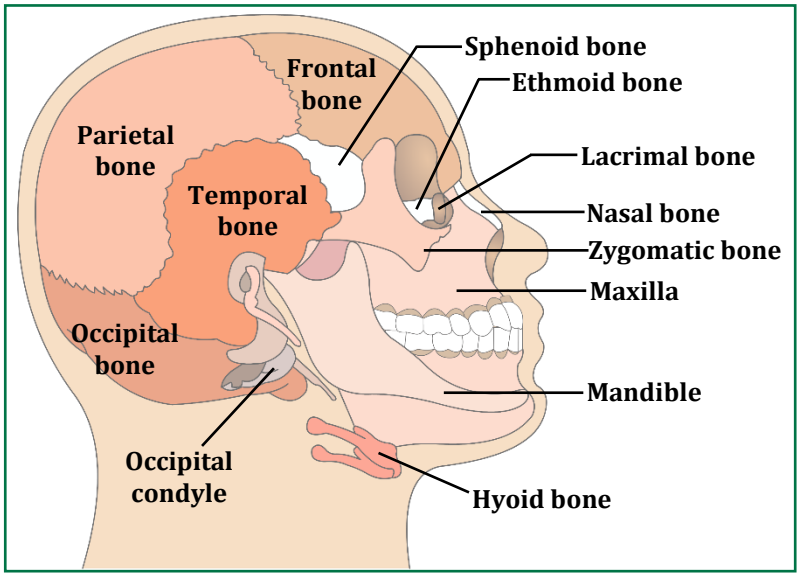
- A single U-shaped bone called **hyoid** is present at the base of the buccal cavity and it is also included in the skull.
- Hyoid bone is the **only bone** which is **not attached with any other bone of the body**.
- **Tongue is attached with hyoid bone**.

Ear Ossicles :

- Each middle ear contains three tiny bones – **Malleus**, **Incus** and **Stapes**, collectively called **Ear Ossicles**.
- **Stapes** is the **smallest bone of our body**.
- The ear ossicles increase the efficiency of transmission of sound waves to the inner ear.

Summary of skull bones and associated bones :

- **SKULL SKELETON**
  - **Skull Bones**
    - **Cranial-8**
      - Fronal-1
      - Parietal-2
      - Temporal-2
      - Occipital-1
      - Ethmoid-1
      - Sphenoid-1
    - **Facial-14**
      - Maxilla-2
      - Palatine-2
      - Zygomatic/Malar-2
      - Nasal-2
      - Lacrymal-2
      - Inferior nasal conchae/Turbinal bones-2
      - Mandible-1
      - Vomer-1
  - **Associated Skull Bones**
    - Hyoid bone-1
    - Ear ossicles-6 (Malleus, Incus, Stapes)



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BEGINNER'S BOX-1 SKULL

1. Skull of Man is :-
(1) Monocondylic (2) Dicondylic
(3) Tricondylic (4) Tetracondylic

2. Total number of skull bones in human :-
(1) 22 (2) 49 (3) 39 (4) 19

3. Single bone of lower jaw in human is :-
(1) Maxilla (2) Mandible (3) Nasal (4) Lacrimal

4. Spinal cord passes to brain through :-
(1) Foramen of Monro (2) Foramen of Magendie
(3) Foramen ovale (4) Foramen of magnum

5. Total number of bones of human face:-
(1) 10 (2) 12 (3) 14 (4) 16

6. Human cranium is made of ..... bones.
(1) 14 (2) 8 (3) 22 (4) 7

7. The skull, vertebral column, sternum and ribs constitute :-
(1) Visceral skeleton (2) Axial skeleton
(3) Appendicular skeleton (4) Exoskeleton

8. Surface for attachment of tongue is :
(1) Palatine (2) Sphenoid (3) Ethmoid (4) Hyoid apparatus

9. Smallest bone in Human is :-
(1) Nasal (2) Patella (3) Stapes (4) Palatine

10. How many occipital condyles do humans possess?
(1) 4 (2) 1 (3) 3 (4) 2

11. Skeletal system consist of :-
(1) Framework of bones only
(2) Framework of cartilages only
(3) Framework of bones and a few cartilages
(4) Framework of epithelial and connective tissue

12. Matrix of cartilage is :-
(1) Solid, pliable and resist compression
(2) Hard and nonpliable
(3) Fibres free
(4) Rich in collagen fibres

13. Which of the following is a function of bone?
(1) Support and protect softer tissues and organs
(2) Production of blood cells
(3) Serve weight bearing functions
(4) All of the above

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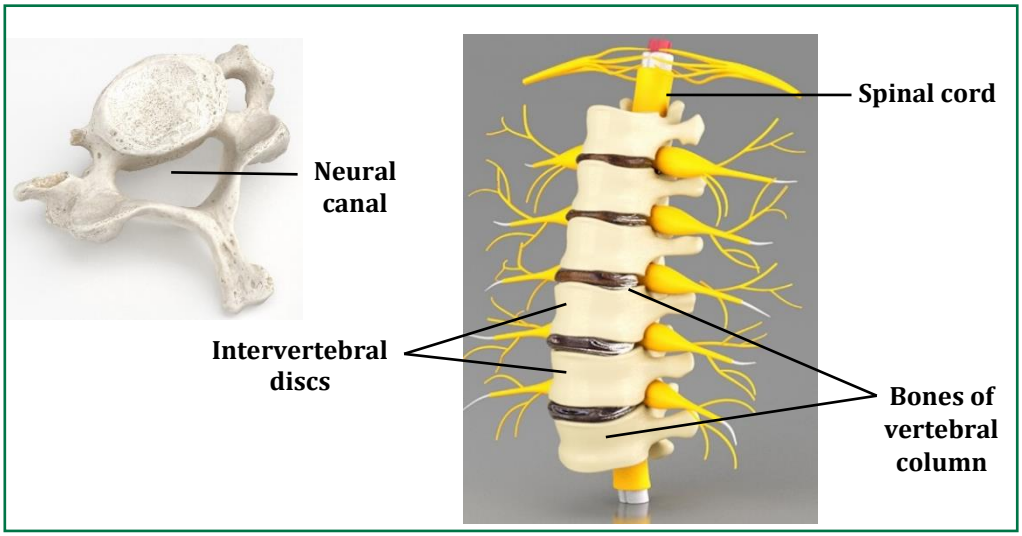
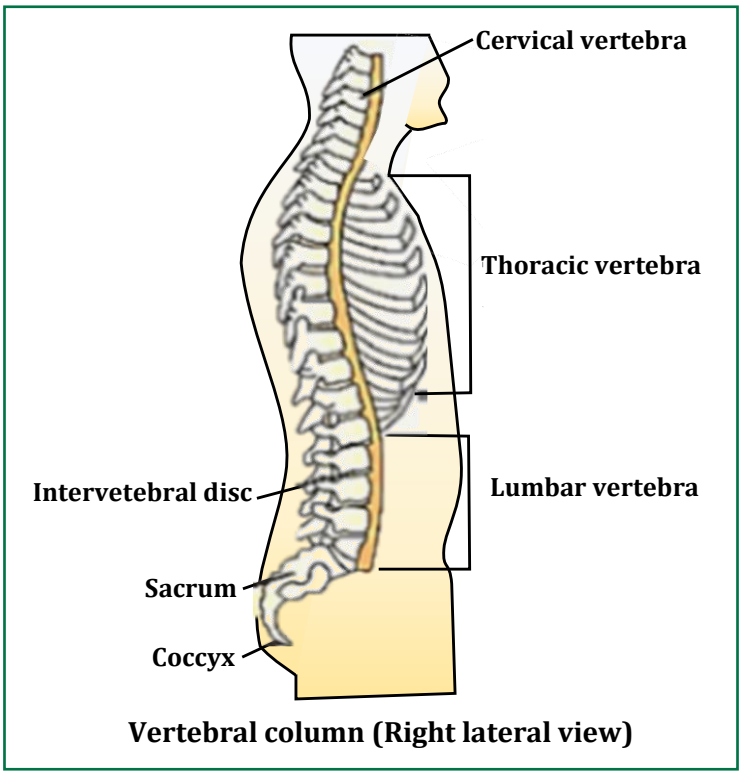
(B) Vertebral Column :

- Our vertebral column is formed by **26 serially arranged** units called **vertebrae** and is dorsally placed. It extends from the base of the skull and constitutes the main framework of the trunk.
- Each vertebra has a central hollow portion (neural canal) through which the spinal cord passes.



- The vertebral column is differentiated into **Cervical (7)**, **Thoracic (12)**, **Lumbar (5)**, **Sacral (1-fused)** and **Coccygeal (1-fused)** regions starting from the skull.



Vertebral column (Right lateral view)

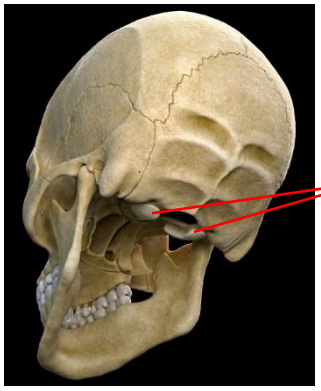
Cervical Vertebrae :

- The number of **cervical vertebrae** are **seven** in almost all mammals including human beings.

Atlas :

- First vertebra is the atlas.
- **Atlas** articulates with the occipital condyles of occipital bone and form condylar joint which is responsible for **downward** and **upward movement**.

Atlas vertebra



Occipital condyles of skull

Atlas vertebra

Occipital condyles of skull

Axis Vertebra :

- Second vertebra is called axis.
- Axis form **pivot joint with atlas**.
- Pivot joint is responsible for **sideways movement**.

Thoracic Vertebrae :

- Thoracic vertebrae in human beings are 12 in number.
- Play an important role to protect the lungs and heart by attaching to the ribcage

Lumbar Vertebrae :

- Lumbar vertebrae are 5 in number.
- Lumbar vertebrae are the heaviest and largest vertebrae
- The lumbar vertebrae's function is to support the great weight of the body and allow certain movements, such as lifting objects.

Sacrum :-

- (1 fused) (5 in number but fused to form one)
- The sacrum forms the posterior pelvic wall and strengthens and stabilizes the pelvis

Coccyx :-

- (1 fused) (4 in number but fused to form one)
- Coccyx provides weight-bearing support to a person in the seated position.

Functions of Vertebral Column :-

(1) The vertebral column protects the spinal cord,
(2) Vertebral column supports the head
(3) Vertebral column serves as the point of attachment for the ribs and musculature of the back.

BEGINNER'S BOX-2 VERTEBRAL COLUMN

1. In camel number of cervical vertebra is :-
(1) 6 (2) 7 (3) 8 (4) 9

2. Long neck of Girraffe or camel is due to:-
(1) More number of cervical vertebra
(2) More length of cervical vertebra
(3) Presence of pads between cervical vertebra
(4) Presence of extra bony plates

3. In humans, coccyx is formed by the fusion of vertebrae :
(1) 3 (2) 4 (3) 5 (4) 6

4. Coccygeal bone is a bone of :
(1) Skull (2) Pectoral girdle (3) Vertebral column (4) Pelvis

5. The number of cervical vertebrae in mammals including human being are
(1) 7 (2) 8 (3) 9 (4) 10

6. The major function of intervertebral disc is
(1) absorb shock (2) String vertebrae together
(3) prevent injuries (4) prevent hyper extension

7. Number of cranial, cervical and thoracic bones in human are ....,..... and ..... respectively.
(1) 14,7,14 (2) 8,14,7 (3) 14,7,12 (4) 8,7,12

8. Which of following helps in rotation of the neck ?
(1) Atlas (2) Axis
(3) Cervical (4) Occipital condyle of skull

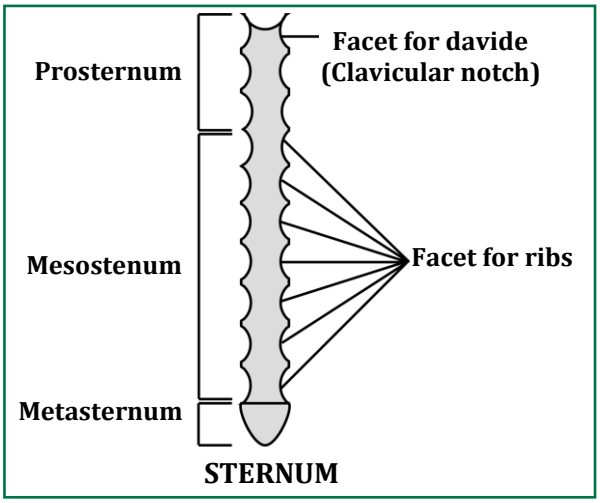
9. Total number of vertebrae in man are :-
(1) 30 (2) 26 (3) 40 (4) 35

10. Sacrum in human is formed by fusion of :-
(1) 3 vertebrae (2) 5 vertebrae (3) 8 vertebrae (4) 6 vertebrae

(C) Sternum and Ribs :

(i) Sternum :

- Sternum is a flat bone on the ventral midline of thorax.
- There are three parts of sternum-
  (i) Superior (anterior) part is the prosternum **(manubrium)**
  (ii) Middle part is the mesosternum **(body)**
  (iii) Inferior (posterior) smallest metasternum **(xiphoid process)**



- The sternum provides spaces for the attachment of the thoracic ribs and abdominal muscles too.
- **The sternum is a favoured site for obtaining samples of haemopoietic tissue during diagnosis of suspected blood diseases.**

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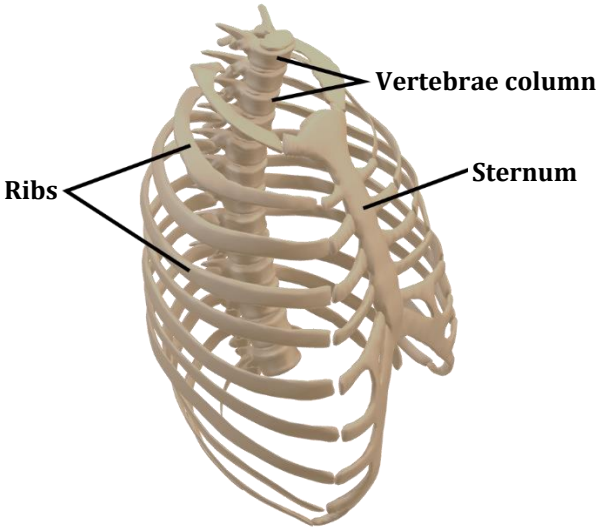
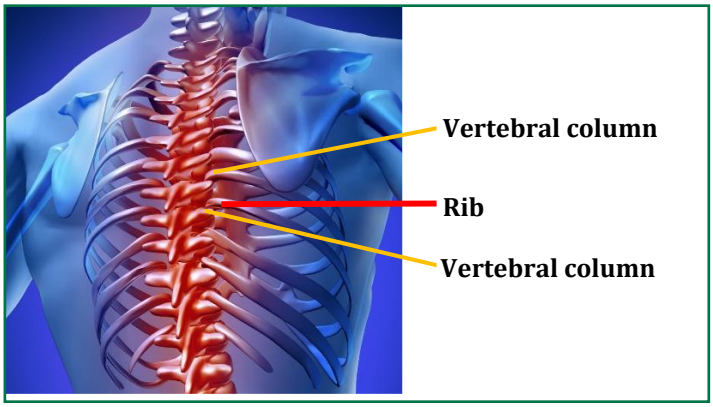
(ii) Ribs :

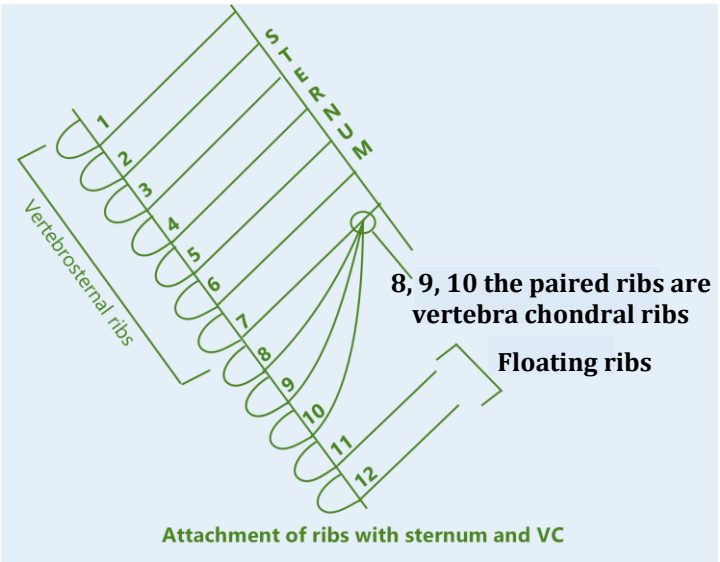
- There are 12 pairs of ribs.
- Each rib is a thin flat bone connected dorsally to the vertebral column and ventrally to the sternum.



- It has two articulation surfaces on its dorsal end and is hence called **bicephalic**.



- First seven pairs of ribs are called true ribs **(Vertebro-sternal ribs)**.
- Dorsally, they (1st to 7th pair of ribs) are attached to the thoracic vertebrae and ventrally connected to the sternum with the help of hyaline cartilage.
- The 8th, 9th and 10th pairs of ribs do not articulate directly with the sternum but join the seventh rib with the help of hyaline cartilage. These are called **vertebrochondral** (false) ribs.
- Last 2 pairs (11th and 12th) of ribs are not connected ventrally and are therefore, called **floating ribs**.
- The thoracic vertebrae, ribs and sternum together form the **rib cage**.


Vertebrosternal ribs
8, 9, 10 the paired ribs are vertebra chondral ribs
Floating ribs
Attachment of ribs with sternum and VC

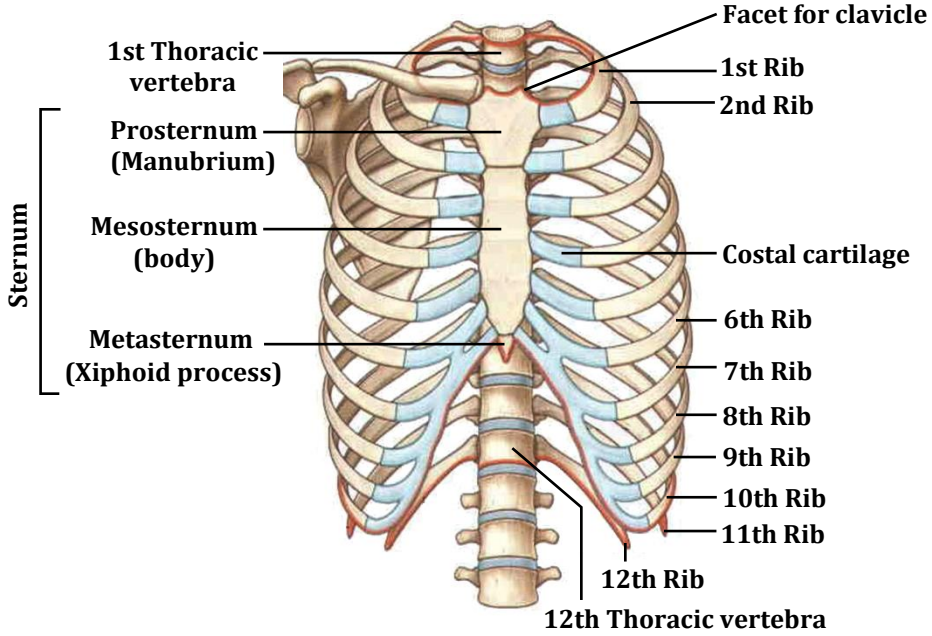
Rib Cage : Thoracic vertebrae, ribs and sternum together form the rib cage .

There are five parts of rib cage :-

(1) Dorsal consist of vertebral column and ribs
(2) Ventral consist of sternum and ribs
(3) Lateral consist of ribs
(4) Anterior consist of neck and clavicle
(5) Posterior consist of diaphragm

Significance of Rib Cage :

- The rib cage protects the organs in the thoracic cavity, assists in respiration, and provides support for the upper extremities. During inspiration the ribs are elevated, and during expiration the ribs are depressed.



Bones of thorax (front view)

BEGINNER'S BOX-3 — STERNUM AND RIBS

1. In man ribs are attached to :-
(1) Clavicle (2) Sternum (3) Cervical (4) Acromion

2. Which connective tissue provides the attachment of the true ribs with sternum?
(1) Hyaline cartilage (2) Areolar tissue
(3) Fibrocartilage (4) Elastic cartilage

3. Ribs which are dorsally attached with vertebral column and ventrally with sternum are called -
(1) True ribs (2) False ribs (3) Floating ribs (4) Strong ribs

4. Number of floating ribs in human :-
(1) 6 pairs (2) 5 pairs (3) 3 pairs (4) 2 pairs

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5. Vertebrochondral ribs in human are :-

(1) 8^{th} , 9^{th} , 10^{th} ribs (2) 7^{th} , 8^{th} , 9^{th} ribs

(3) 9^{th} , 10^{th} , 11^{th} ribs (4) 6^{th} , 7^{th} , 8^{th} ribs

6. The total number of ribs in human body is :

(1) 10 (2) 12 (3) 24 (4) 36

7. Match the following columns.

Column-A		Column-B	
A	True ribs	i	06
B	False ribs	ii	04
C	Floating ribs	iii	14

(1) A-i, B-ii, C-iii (2) A-iii, B-i, C-ii

(3) A-iii, B-ii, C-i (4) A-ii, B-iii, C-i

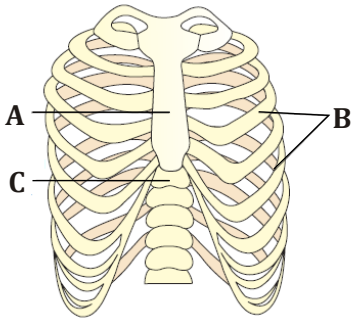
8. Identify A, B and C in the given diagram and choose the correct option.

(1) A–Sternum, B–Vertebral column, C–Ribs

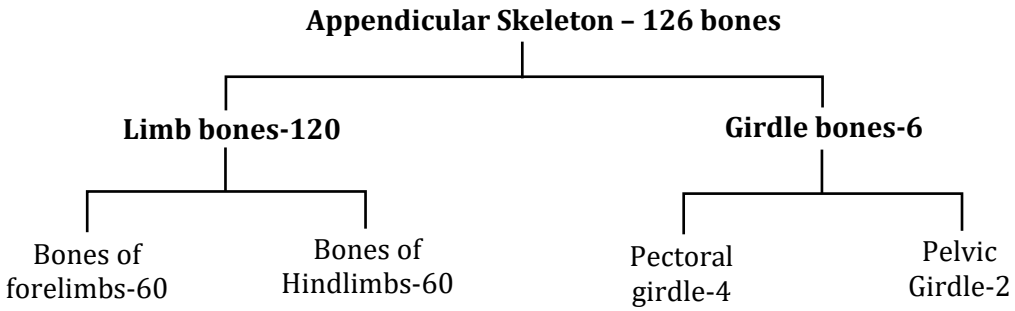
(2) A–Ribs, B–Vertebral column, C–Sternum

(3) A– Ribs, B– Sternum, C–Vertebral column

(4) A–Sternum, B–Ribs, C–Vertebral column



3. Appendicular Skeleton :



- The bones of the limbs along with their girdles constitute the appendicular skeleton.
- Each limb is made of 30 bones.

(A) Forelimbs Bones :

- The bones of the hand (fore limb) are **humerus**, **radius** and **ulna**, **carpals** (wrist bones – 8 in number), **metacarpals** (palm bones – 5 in number) and **phalanges** (digits – 14 in number).

Humerus :

- The humerus is a long bone in the arm that runs from the shoulder to the elbow.

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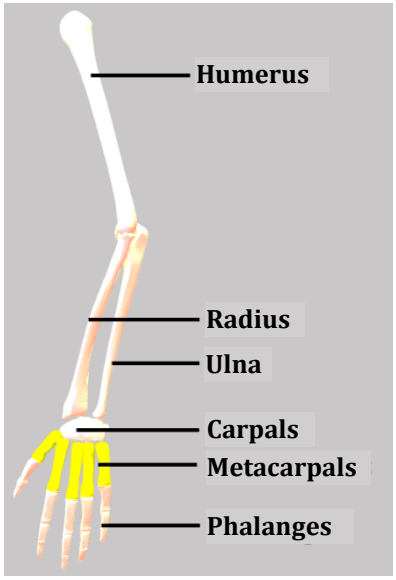
Radius & Ulna :

- The **radius** or **radial bone** is one of the two large bones of the forearm, the other being the **ulna.** It extends from the lateral side of the elbow to the thumb side of the wrist and runs parallel to the **ulna.**
- The **ulna** is usually slightly longer than the **radius**, but the **radius** is thicker. Therefore the **radius** is considered to be the larger of the two.



Carpals : Carpals are 8 in number in each fore limb.

Meta Carpals : Each fore limb consist of 5 Metacarpals.

Phalanges :

- Each fore limb consist of 14 phalanges.
- Digital formula for phalanges is 2, 3, 3, 3, 3.

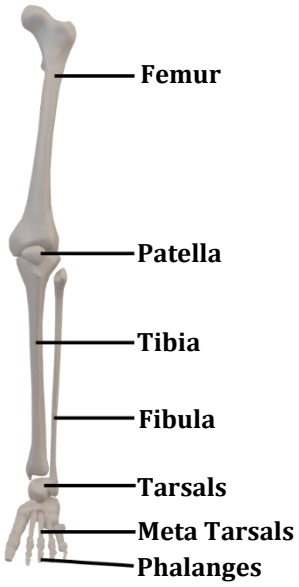
(B) Hindlimbs Bones :

- **Femur** (thigh bone – the longest bone), **tibia** and **fibula**, **tarsals** (ankle bones – 7 in number), **metatarsals** (5 in number) and **phalanges** (digits – 14 in number) are the bones of the legs (hind limb).
- A cup shaped bone called **patella** cover the knee ventrally **(knee cap)**.

Femur : Thigh bone – the longest bone.

Patella :

- A cup shaped bone called patella cover the knee ventrally (knee cap).
- Only **sesamoid** hind limb **bone is patella**.



Tibia :

- Medial & larger bone of the leg.
- Upper end articulates with femur bone.

Fibula :

- Lateral & smaller bone of the leg.
- Its upper end articulates with the tibia.
- It does not participate in the formation of knee joint.
- Its lower end fused with tibia and form inferior tibiofibular joint (immovable joint)

Tarsals :

- Tarsal bones are much larger & stronger than carpal bones because they have to support & distribute body weight.
- Total number of tarsal bones is seven.

Meta Tarsals : Meta tarsal bones which are numbered medial to lateral.

Phalanges :

- 14 Phalanges, 2 for great toe & 3 each for other four toes.
- As compared to Phalanges of hand, these are small in size.
- Digital formula = 2,3,3,3,3

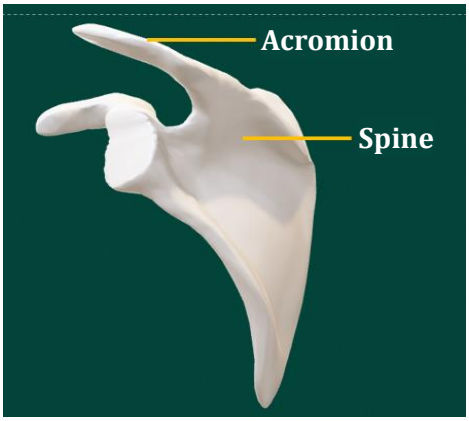
The arrangement and number of bones in the lower limb are similar to those of the upper limb. However, the bones of the lower limb are adapted for weight bearing and locomotion, they may be somewhat different in shape and articulate differently than the comparable bones of the upper limb.

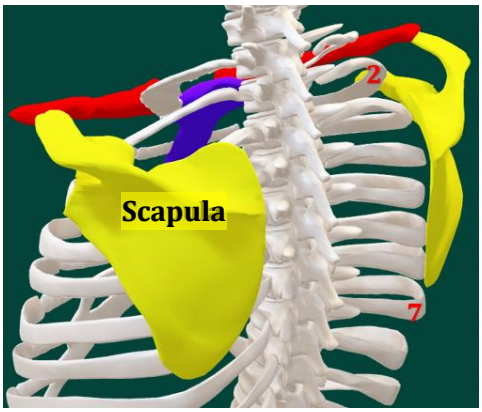
(C) Girdle Bones :

- Pectoral and Pelvic girdle bones help in the articulation of the **upper limbs (Fore limb bones)** and the **lower limbs (Hindlimb Bones)** respectively with the axial skeleton.

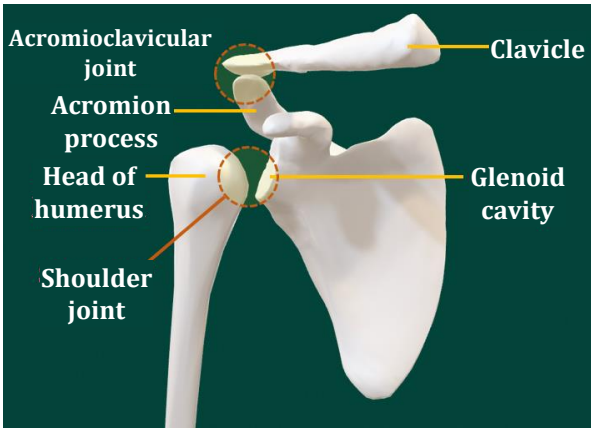
Pectoral Girdle :

- Consists of two halves, helps in the articulation of the upper limbs with the axial skeleton.
- Each half of pectoral girdle consists of a **clavicle** (Collar bone) and a scapula.
- **Scapula** is a large **triangular flat bone** situated in the dorsal part of the thorax between the second and the seventh ribs.
- The dorsal, flat, triangular body of scapula has a slightly **elevated ridge** called the **spine** which projects as a flat, expanded process called the **acromion process**.





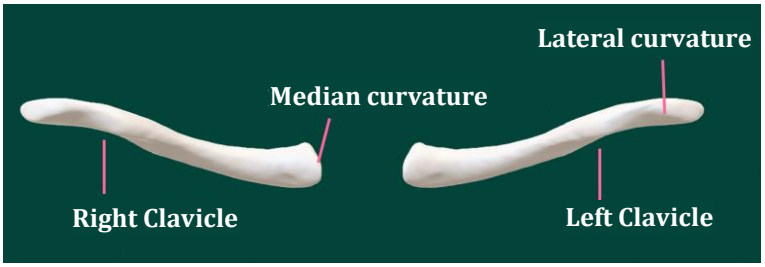
- Clavicle articulates with Acromion process of scapula to form acromioclavicular joint.



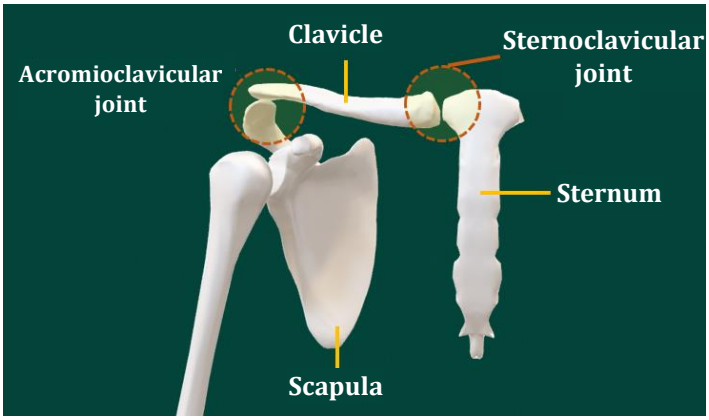
- Below the acromion process is a depression called the glenoid cavity.
- Head of humerus fits in glenoid cavity of scapula and form shoulder joint.

Clavicle :

- Each clavicle is a long slender bone with two curvatures. This bone is commonly called the collar bone.

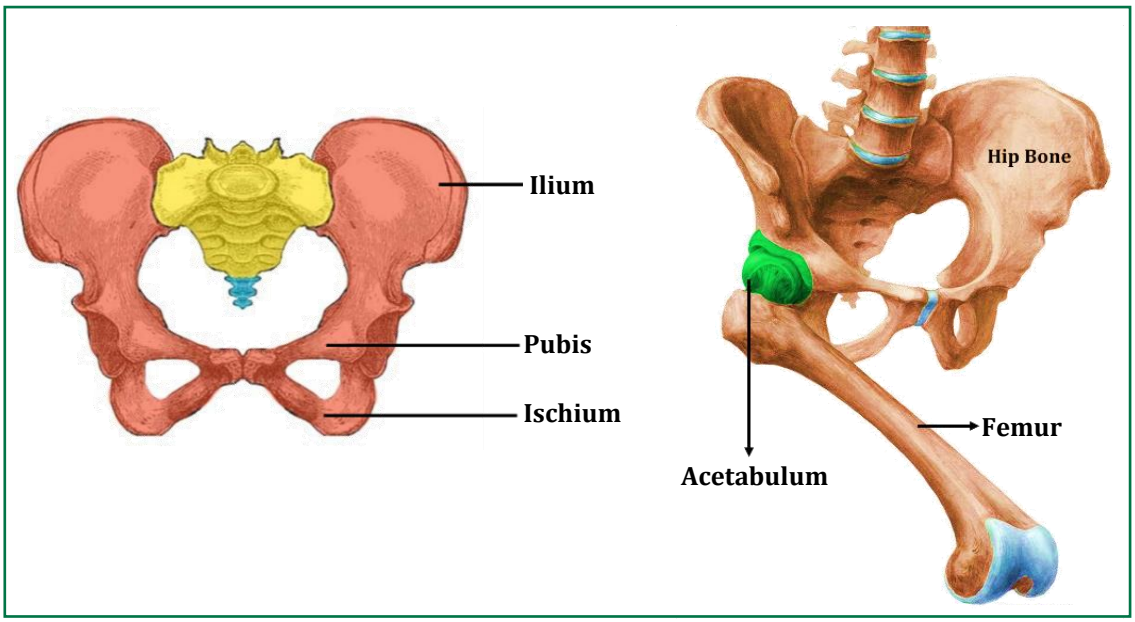


- Lateral curvature of clavicle form acromioclavicular joint with acromion process of scapula whereas median curvature of clavicle form sternoclavicular joint with sternum.

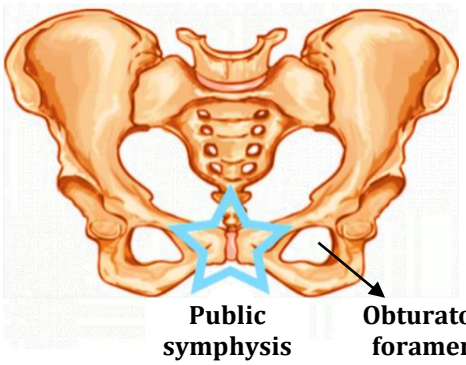


Pelvic Girdle :

- Pelvic girdle consists of **two coxal bones**.
- Each coxal bone is formed by the fusion of three bones – **ilium, ischium** and **pubis**.
- At the point of fusion of illium, ischium, pubis is a cavity called **acetabulum** to which the thigh bone articulates.



- The two halves of the pelvic girdle meet ventrally to form the **pubic symphysis** containing fibrous cartilage.
- A large opening in the hip bone between the pubis and the ischium called **Obturator foramen**.
- Obturator foramen allows a few vessels and nerves to pass out from the pelvic cavity to communicate with the lower limb.



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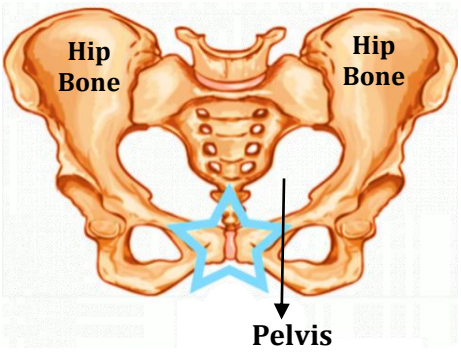
Pelvis :

- The **pelvis** is the lower part of the trunk, between the abdomen and the thighs (sometimes also called **pelvic region**), together with its embedded skeleton (sometimes also called **bony pelvis** or **pelvic skeleton**).
- Reproductive organs some part of large intestine and urinary bladder are present in this region.



Differences between male and female pelvis

Features	Female Pelvis	Male Pelvis
1. General width	Hips are wider	Hips are narrower
2. Pubis	Longer, More rectangular	Short, Triangular
3. Sacrum	Shorter, wider	Narrower, Longer

BEGINNER'S BOX-4 — APPENDICULAR SKELETON

1. Total number bones in appendicular skeleton of human :-
(1) 126 (2) 80 (3) 44 (4) 33

2. Longest bone of human skeleton :-
(1) Femur (2) Humerus (3) Tibia (4) Radius

3. Digital formula of hand of human is :-
(1) 23333 (2) 03322 (3) 33332 (4) 02233

4. Number of tarsal bones in human in each hind limb :-
(1) 2 (2) 7 (3) 6 (4) 5

5. Which of the following is the bone of forelimb?
(1) Humerus (2) Femur (3) Tibia (4) Fibula

6. Os Innominatum consist of :-
(1) pubis (2) ischium (3) ilium (4) all of the above

7. A cup shaped cavity for articulation of femur head is :-
(1) acetabulum (2) glenoid cavity
(3) sigmoid notch (4) obturator foramen

8. Scapula is part of :-
(1) skull (2) pelvic girdle
(3) pectoral girdle (4) vertebral column

9. Obturator foramen present between:-
(1) Ilium & Ischium (2) Ischium & Pubis
(3) Ilium & pubis (4) Scapula & Clavicle

10. Number of bones present in a forelimb of human :
(1) 30 (2) 32 (3) 35 (4) 40

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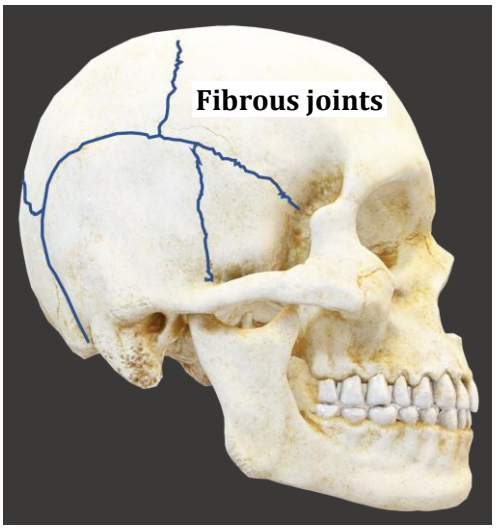
4. Joints :

- **Joints** are essential for all types of movements involving the bony parts of the body.
- Locomotory movements are no exception to this. Joints are points of contact between bones, or between bones and cartilages.
- Force generated by the muscles is used to carry out movement through joints, where the joint acts as a **fulcrum**.
- The movability at these joints vary depending on different factors.
- Joints have been classified into three major structural forms, namely, **fibrous**, **cartilaginous** and **synovial.**

(A) Fibrous Joints :

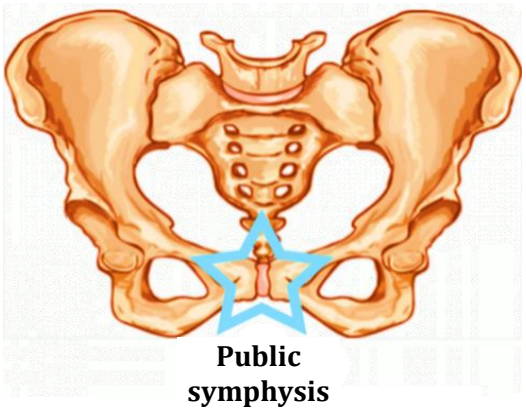
- **Fibrous joints** do not allow any movement.
- This type of joint is shown by the **flat skull bones** which fuse end-to-end with the help of **dense fibrous connective tissues** in the form of **sutures**, to form the **cranium**.



(B) Cartilaginous Joints :

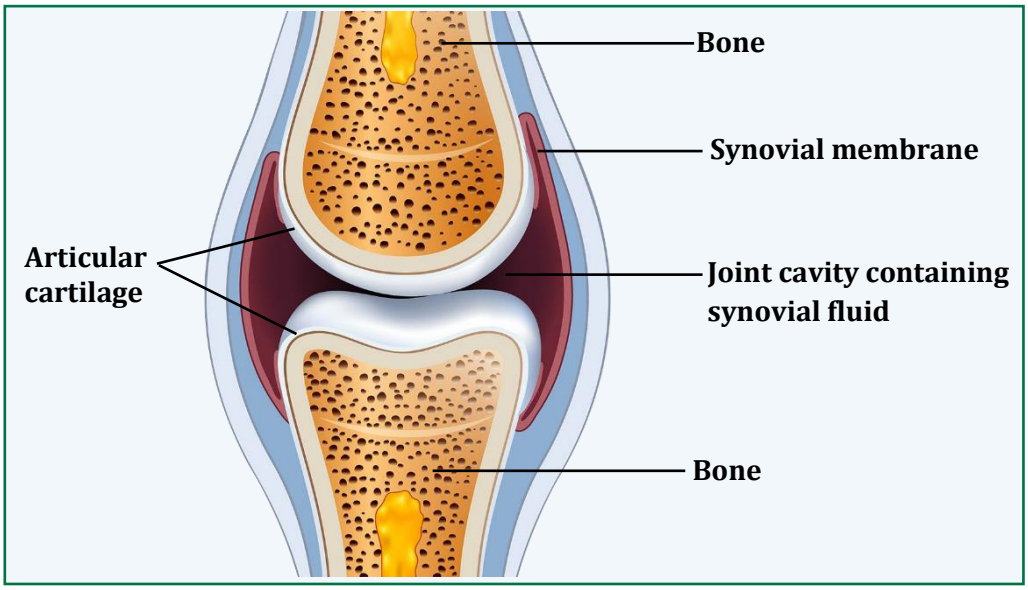
- In **cartilaginous joints (SYNCHONDROSIS)**, the bones involved are joined together with the help of cartilages.
- The joint between the **adjacent vertebrae** in the vertebral column is of this pattern and it permits limited movements.

The two halves of the pelvic girdle meet ventrally to form the pubic symphysis containing fibrous cartilage.



(C) Synovial Joints :

- **Synovial joints (DIARTHROSIS)** are characterised by the presence of a fluid filled **synovial cavity** between the articulating surfaces of the two bones. Such an arrangement allows considerable movement.
- These joints help in locomotion and many other movements.



Examples of Synovial joints: -

- Ball and socket joint (between humerus and glenoid cavity of pectoral girdle).
- Ball and socket joint (between femur and acetabulum of pelvic girdle).
- Hinge joint (knee joint).
- Pivot joint (between atlas and axis).
- Gliding joint (between the carpals).
- Saddle joint (between carpal and metacarpal of thumb) are some examples.
- Hinge joint (Between phalanges).
- Hinge joint (Elbow joint).
- Condylar joint (Between atlas and occipital condyles of occipital bones)

5. Disorders of Skeletal System :

- **Arthritis:** Inflammation of joints.
- **Osteoporosis:** Age-related disorder characterised by decreased bone mass and increased chances of fractures. Decreased levels of estrogen is a common cause.
- **Gout:** Inflammation of joints due to accumulation of uric acid crystals.
- **Sprain:** Ligament injury
- fractures. Decreased level of estrogen is a common cause.

BEGINNER'S BOX-5 JOINTS AND DISORDERS

1. Elbow joint is an example of: -
(1) Ball & socket joint (2) Pivot joint
(3) Gliding joint (4) Hinge joint

2. The shoulder joint is a ball and socket joint between: -
(1) Glenoid cavity of pectoral girdle & head of humerus
(2) Coronoid process of pectoral girdle & head of humerus
(3) Acetabulum cavity of pectoral girdle & head of humerus
(4) Between radius, ulna and humerus

3. Head of humerus is articulated with pectoral girdle by a joint: -
(1) Hinge (2) Ball and socket
(3) Immovable (4) Pivot joint

4. Which one is a ball and socket joint?
(1) Knee joint (2) Elbow joint
(3) Humerus and pectoral girdle (4) Atlas & Axis

5. Which one of the following is correctly matched?
(1) Hinge joint – between vertebrae
(2) Pivot joint –between atlas and axis
(3) Fibrous joint – between phalanges
(4) Cartilaginous joint – skull bones

6. Bones become fragile in
(1) Gout (2) Osteoporosis
(3) Arthritis (4) Myasthenia gravis

7. Symphysis is made of
(1) Fibrocartilage (2) Synovial fluid
(3) Elastic cartilage (4) Hyaline cartilage

8. Which one is cartilaginous joint?
(1) Synchondrosis (2) Symphysis
(3) Diarthrosis (4) Both (1) and (2)

9. Deposition of uric acid crystals within the synovial joint causes
(1) Gout (2) Paralysis
(3) Osteoarthritis (4) Rheumatoid arthritis

10. The example of pivot joint is-
(1) Hip joint (2) Ankle joint
(3) Between atlas and axis (4) Metacarpophalengeal joint

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BEGINNER'S BOX — ANSWERS KEY

BEGINNER'S BOX-1	Que.	1	2	3	4	5	6	7	8	9	10
	Ans.	2	1	2	4	3	2	2	4	3	4
	Que.	11	12	13							
	Ans.	3	1	4							

BEGINNER'S BOX-2	Que.	1	2	3	4	5	6	7	8	9	10
	Ans.	2	2	2	4	1	1	4	2	2	2

BEGINNER'S BOX-3	Que.	1	2	3	4	5	6	7	8
	Ans.	2	1	1	4	1	3	2	4

BEGINNER'S BOX-4	Que.	1	2	3	4	5	6	7	8	9	10
	Ans.	1	1	1	2	1	4	1	3	2	1

BEGINNER'S BOX-5	Que.	1	2	3	4	5	6	7	8	9	10
	Ans.	4	1	2	3	2	2	1	4	1	3

ESSENCE

HUMAN SKELETON - 206 bones				
Axial-80		Appendicular-126		
AXIAL SKELETON - 80 BONES				
SKULL SKELETON- 29		**STERNUM - 01**	**RIBS - 24**	**VERTEBRAL COLUMN - 26**
SKULL BONES - 22			True - 14	Cervical - 7
Cranial - 8	Facial - 14		False - 6	Thoracic - 12
Frontal - 1	Maxilla - 2		Floating-4	Lumbar - 5
Parietal - 2	Palatine -2			Sacral - 5
Temporal - 2	Zygomatic - 2			Coccygeal - 4
Occipital - 1	Nasal - 2			
Ethmoid - 1	Lacrimal - 2			
Sphenoid -1	Inferior Turbinals - 2			
	Mandible - 1			
	Vomer - 1			
ASSOCIATED SKULL BONES - 07				
Hyoid Bone - 1		Ear ossicles - 2x3 (Malleus, Incus, Stapes)		

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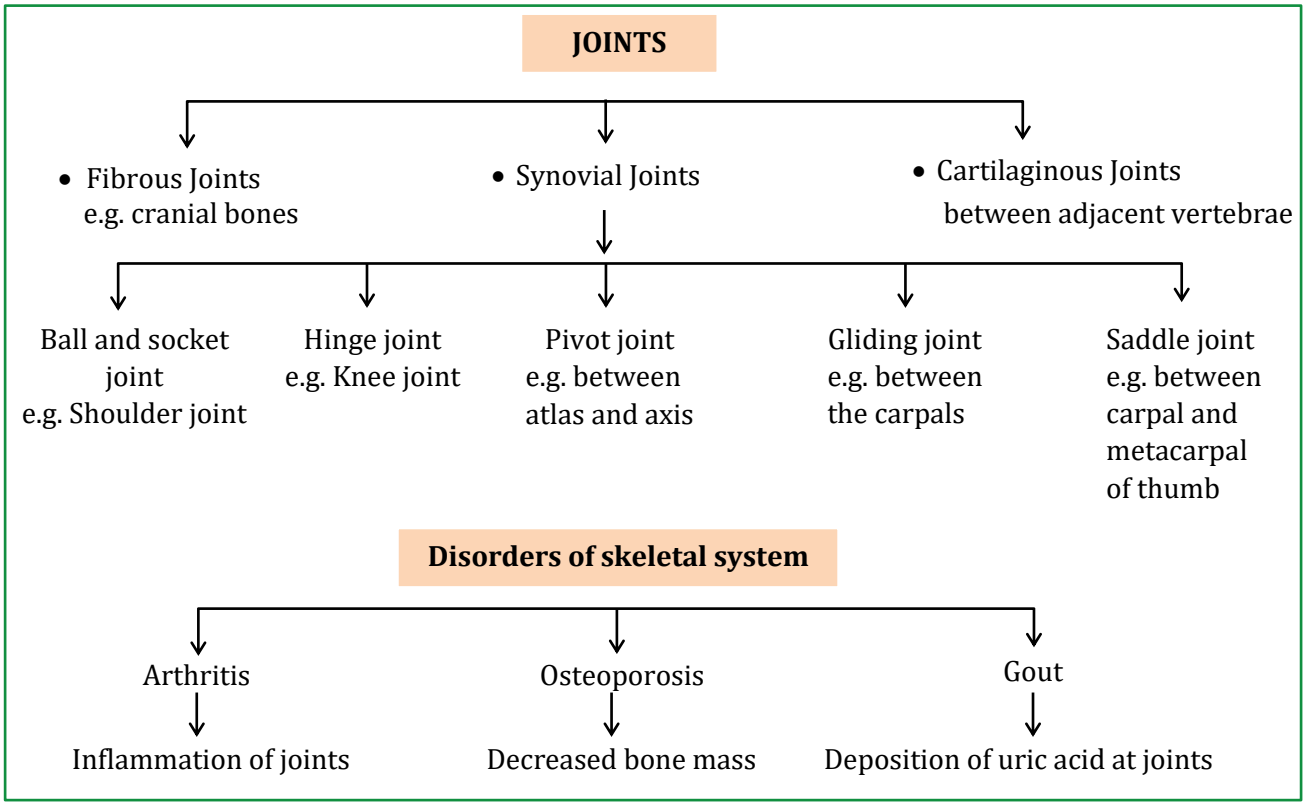
APPENDICULAR SKELETON - 126 BONES			
LIMB BONES - 120		**GIRDLE BONES - 06**	
Fore limb Bones - 60	Hind limb Bones - 60	Pectoral Girdle - 4	Pelvic Girdle - 2
Humerus – 1×2	Femur – 1×2	Scapula - 1×2	
Radius – 1×2	Patella - 1×2	Clavicle - 1×2	
Ulna - 1×2	Tibia - 1×2		(is formed by 2 hip bones and each hip bone is formed by fusion of 3 bones ilium, ischium and pubis)
Carpals - 8×2	Fibula - 1×2		
Metacarpals - 5×2	Tarsals - 7×2		
Phalanges - 14×2	Metatarsals - 5×2		
	Phalanges - 14×2		



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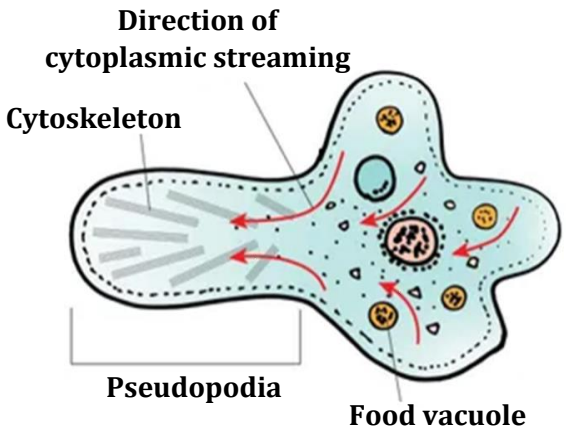
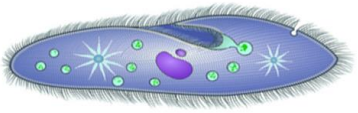
05 Locomotion & Movement (Muscles)

1. Introduction :

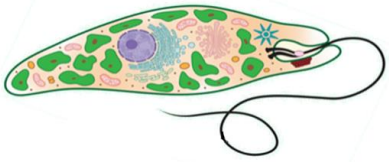
- Movement is one of the significant features of living beings.
- Animals and plants exhibit a wide range of movements.
- Streaming of protoplasm in the unicellular organisms like *Amoeba* is a simple form of movement.



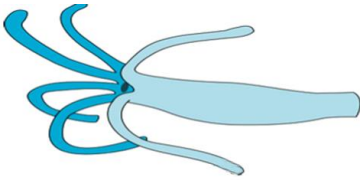
- Movement of cilia, flagella and tentacles are shown by many organisms.



Cilia in Paramoecium



Flagella in Euglena



Tentacles in *Hydra*

- Human beings can move limbs, jaws, eyelids, tongue, etc.
- Some of the movements result in a change of place or location. Such voluntary movements are called locomotion. Walking, running, climbing, flying, swimming are all some forms of locomotory movements.
- Locomotory structures need not be different from those affecting other types of movements.
  For example, in *Paramoecium*, cilia helps in the movement of food through cytopharynx and in locomotion as well.
  Ciliary movements in our respiratory tract.
- *Hydra* can use its tentacles for capturing its prey and also use them for locomotion.
- We use limbs for changes in body postures and locomotion as well.
- The above observations suggest that movements and locomotion cannot be studied separately.
- The two may be linked by stating that all locomotions are movements but all movements are not locomotions.

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- Locomotion is generally for search of food, shelter, mate, suitable breeding grounds, favourable climatic conditions or to escape from enemies/predators.

2. Types of Movements :

Cells of human body exhibit mainly three types of movements
(1) Ciliary
(2) Amoeboid
(3) Muscular

(A) Ciliary Movement :

- It occurs in most of our internal organs which are lined by ciliated epithelium.
  e.g. The coordinated movements of cilia in the trachea help us in removing dust particles and some of the foreign substances inhaled along with the atmospheric air.
- Passage of ova through the female reproductive tract is also facilitated by the ciliary movement.

(B) Amoeboid Movement :

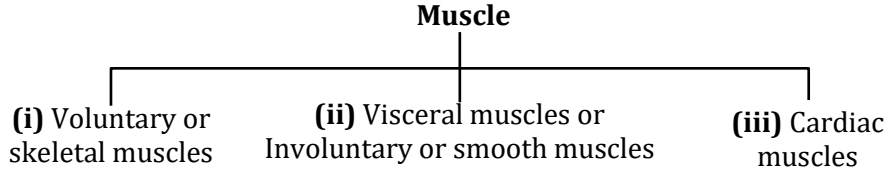
- Some specialised cells in our body like macrophages and leucocytes in blood exhibit amoeboid movement.
- It is effected by pseudopodia formed by the streaming of protoplasm (as in Amoeba).
- Cytoskeletal elements like microfilaments are also involved in amoeboid movement.

(C) Muscular Movement :

- Locomotion requires a perfect coordinated activity of muscular, skeletal and neural systems.
- The contractile property of muscles are effectively used for locomotion and other movements by human beings and majority of multicellular organisms.
- Movement of our limbs, jaws, tongue etc. require muscular movement.
- Multicellular animals movements are the result of a special kind of tissue called **muscular tissue (muscle)**.
- Study of muscles known as **Myology/Sarcology**.

3. Origin of Muscles :

- Origin of muscles is - **mesoderm** except few muscles.
- Muscle of Iris, ciliary body & myoepithelial cell of sweat gland develop from **Ectoderm**.
- Main characteristics of muscle are **excitability, contractility** and **extensibility**.
- Muscles constitutes around **40% to 50%** of adult body mass in an average healthy person.
- Three types of muscles are found in the body. (On the basis of position/location)



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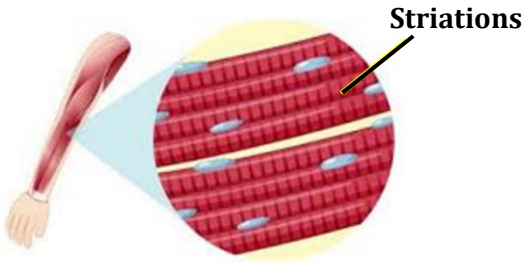
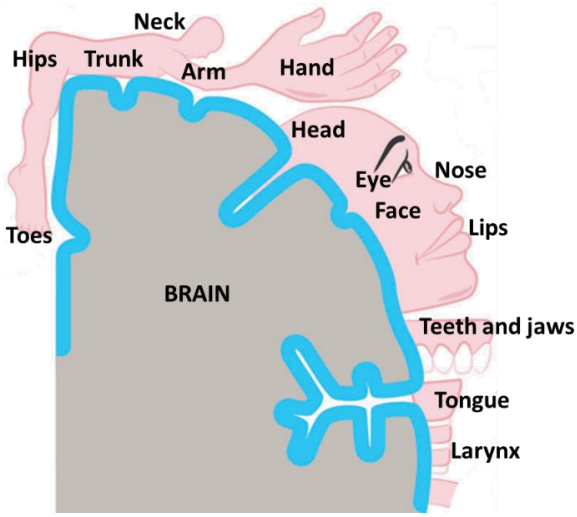
4. Muscles :

(A) Skeletal Muscles :

- Skeletal muscles are closely associated with the **skeletal components** of the body.
- They have a striped appearance under the microscope and hence are called **striated muscles**.

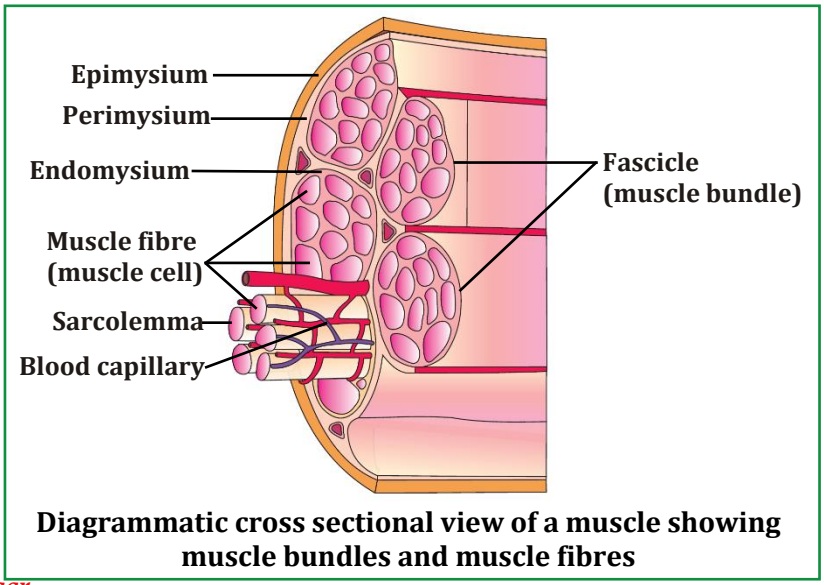


- As their activities are under the voluntary control of the nervous system, they are known as **voluntary muscles** too.



- They are primarily involved in locomotory actions and changes of body postures.

Structure of Skeletal Muscles :



Diagrammatic cross sectional view of a muscle showing muscle bundles and muscle fibres

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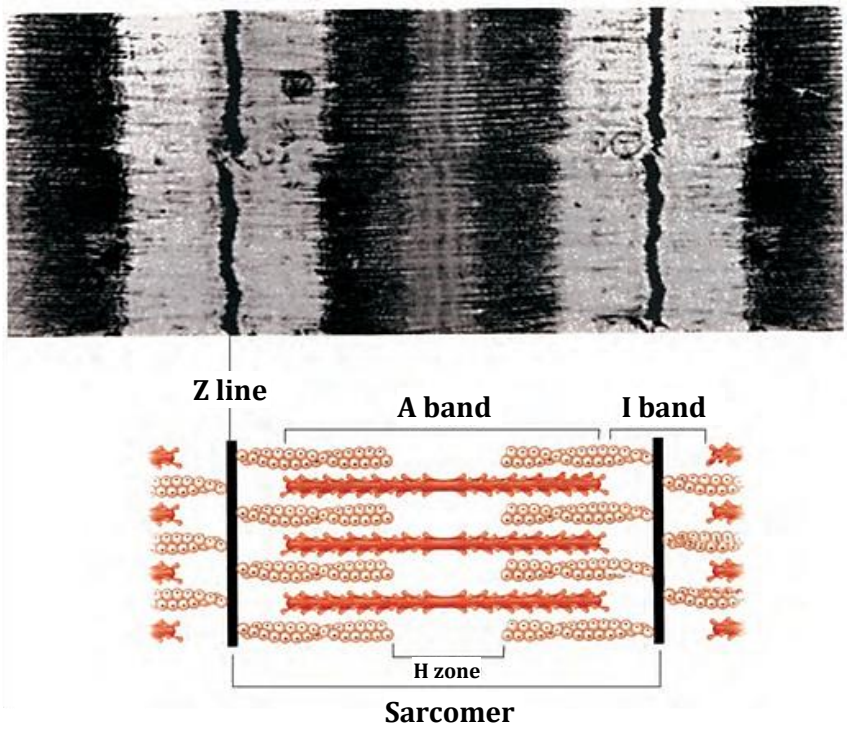
Diagrammatic cross-sectional view of a muscle showing muscle bundles and muscle fibres



Diagrammatic representation of anatomy of a muscle fibre showing a sarcomere

(i) Fine Structure of Muscle Fibre :

- Skeletal muscle fibre is cylindrical or tubular in shape and is long and Unbranched.
- The outer membrane of muscle fibre is called **sarcolemma**.
- This cell membrane contain collagen fibres.
- Each muscle fibre contain multinucleated sarcoplasm.
- Nucleus & sarcoplasm are found in peripheral part.
- Myofibril are arranged in parallel rows & form the dark & light line.
- These lines are found in alternate order.
- These lines are made up of actin & myosin protein. Both proteins are filamentous proteins.
- Actin filaments are thin while myosin filaments are thick.
- Light line or band is made up of only actin filament, these band are mono-refractive in polarised light so it is called **Isotropic band** (I band).
- In the centre of each 'I' band is an elastic fibre called 'Z' line which bisects it.
- The thin filaments are firmly attached to the 'Z' line. The thick filaments in the 'A' band are also held together in the middle of this band by a thin fibrous membrane called 'M' line.
- The 'A' and 'I' bands are arranged alternately throughout the length of the myofibrils. The portion of the myofibril between two successive 'Z' lines is considered as the functional unit of contraction and is called a **Sarcomere**.
- In a resting state, the edges of thin filaments on either side of the thick filaments partially overlap the free ends of the thick filaments leaving the central part of the thick filaments.
- This central part of thick filament, not overlapped by thin filaments is called the **'H' zone**.
- **Sarcomere** is considered as the **functional unit** of contraction.

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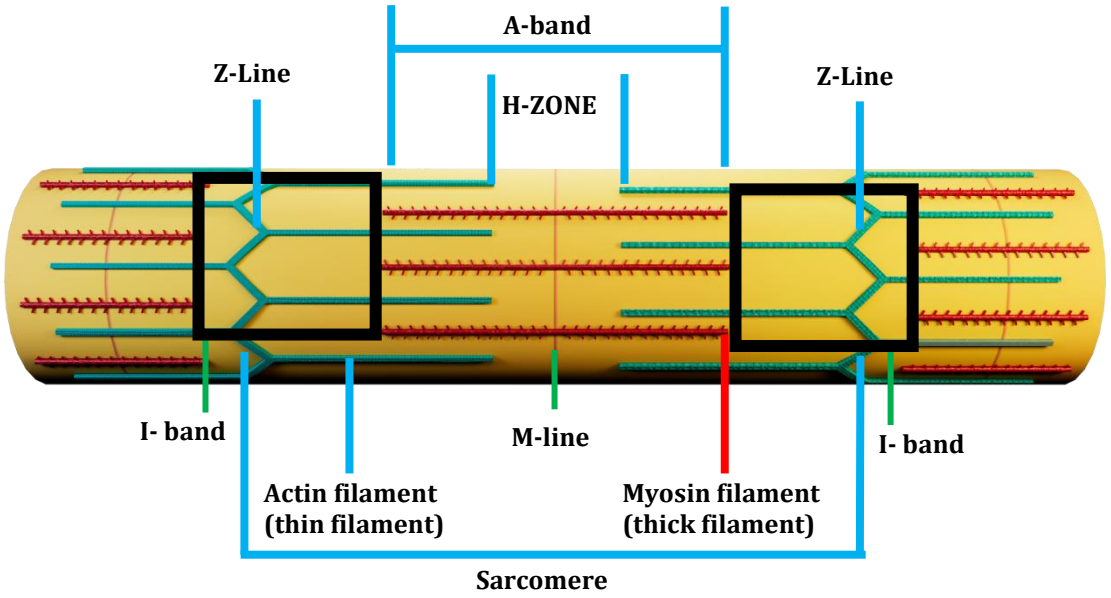


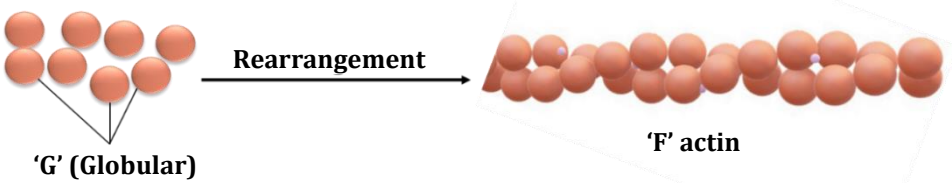
Sarcomere = 1A band + two half I band
The Length of Sarcomere is 2.5 µm.
(I band = 1µm, myosin = 1.5 µm)

- 1 Myosin filament is surrounded by 6 Actin filaments & 1 Actin filament is surrounded by 3 Myosin filaments.
- Z-disc is made up of actinin protein.

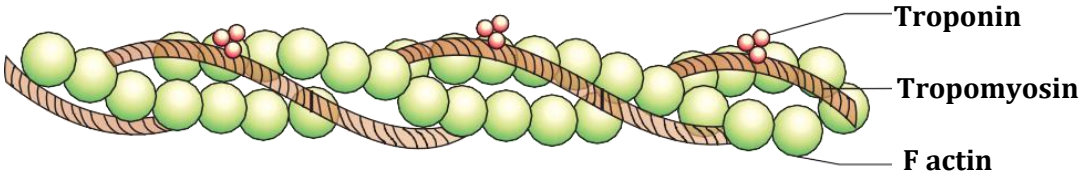
(ii) Structure of Contractile Protein :

(a) Actin (Thin) Filament) :

- Each actin (thin) filament is made up of two 'F' (filamentous) actins helically wound to each other.
- Each 'F' actin is a polymer of monomeric 'G' (Globular) actins.



- Two filaments of another protein, tropomyosin also run close to the 'F' actins throughout its length.
- A complex protein Troponin is distributed at regular intervals on the tropomyosin.
- In the resting state a subunit of troponin masks the active binding sites for myosin on the actin filaments.



An actin (thin) filament

Troponin is made up of three subunit.
(a) Troponin I (Inhibitory site)
(b) Troponin T (Tropomyosin site)
(c) Troponin C (Ca^{+2} binding site)

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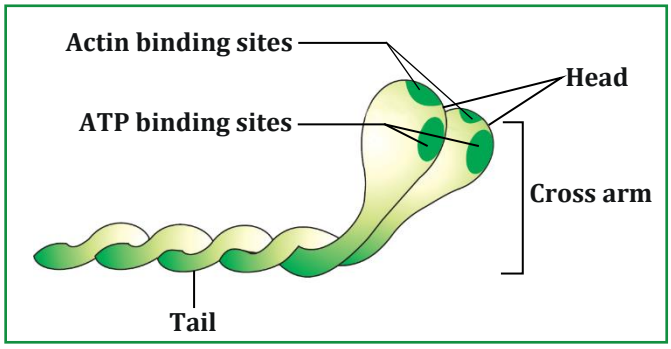
(b) Myosin (Thick) Filament :

- Each myosin (thick) filament is also a polymerised protein.
- Many monomeric proteins called Meromyosins constitute one thick filament.
- Each meromyosin has two important parts, a globular head with a short arm and a tail, the former being called the heavy meromyosin (HMM) and the latter, the light meromyosin (LMM).
- The HMM component, i.e.; the head and short arm projects outwards at regular filament and is known as cross arm.
- The globular head is an active **ATPase enzyme** and has binding sites for ATP and active sites for actin.



Myosin monomer (Meromyosin)

BEGINNER'S BOX-1

INTRODUCTION, STRUCTURE OF SKELETAL MUSCLE

1. Cells of human body does not exhibit which of the following type of movement?
(1) flagellated (2) ciliary (3) muscular (4) amoeboid

2. In the trachea _____ help us in removing dust particles and some of the foreign substances inhaled along with the atmospheric air.
(1) villi (2) microvilli (3) cilia (4) brush border epithelium

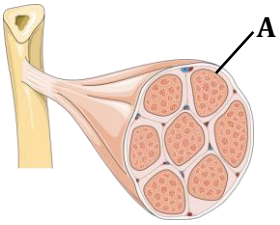
3. Movement of our limbs, jaws, tongue etc. require -
(1) joints (2) muscles (3) tendons (4) ligaments

4. Origin of Muscles is-
(1) ectodermal (2) endodermal (3) mesodermal (4) ecto-Endodermal

5. Activities of Smooth muscles are classified as-
(1) voluntary (2) involuntary (3) both (4) none of the above

6. The store house of calcium ions in the muscle fibres is -
(1) epimysium (2) fascicle (3) collagen fibres (4) sarcoplasmic reticulum

7. Identify the correct labelling in the following diagram-



(1) fascicle
(2) epimysium
(3) perimysium
(4) syncytium

8. This central part of thick filament, not overlapped by thin filaments is called-
(1) 'H' zone (2) 'I' zone (3) 'M' Line (4) 'A' Band

9. Type of movement shown by macrophages is :
(1) Amoeboid (2) Ciliary (3) Muscular (4) Flagellar

10. From outer to inner correct sequence of connective tissue layers covering a muscle fibre is :
(1) Epimysium → Perimysium → Endomysium
(2) Perimysium → Epimysium → Endomysium
(3) Epimysium → Endomysium → Perimysium
(4) Perimysium → Endomysium → Epimysium

11. Monomeric form of actin is called –
(1) F-actin (2) G-actin (3) M-actin (4) A-actin

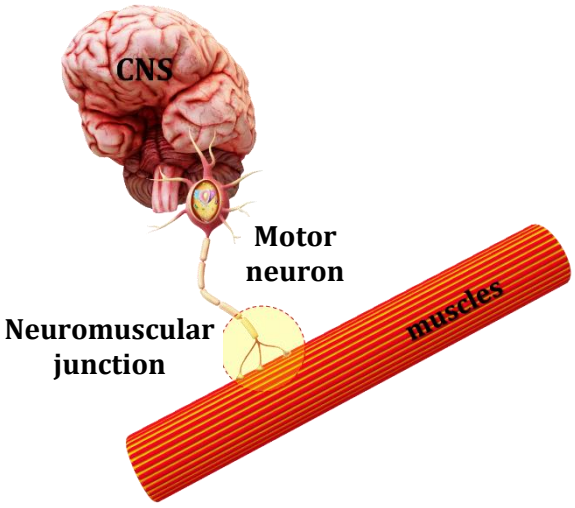
12. The binding of calcium with a subunit of (__A__) on actin filaments removes the masking of active sites for (__B__).
(1) A = Troponin, B = Myosin (2) A = Myosin, B = Tropomyosin
(3) A = Actin, B = Tropomyosin (4) A = Troponin, B = Actin

13. Components of heavy meromyosin are –
(1) Head & cross arm (2) Head & short arm
(3) Head & tail (4) Cross arm & tail

14. The neuromuscular junction or motor-end plate comprises of :-
(1) The junction between a sensory neuron and the sarcolemma of the muscle fibre.
(2) The junction between a motor neuron and the sarcolemma of the muscle fibre.
(3) The junction between a motor neuron and sensory neuron.
(4) The junction between two muscle fibres.

15. A neural signal reaching this junction releases a neurotransmitter (_____) which generates an action potential in the sarcolemma. Identify the neurotransmitter :-
(1) Adrenaline (2) Serotonin (2) Glutamate (4) Acetylcholine

(iii) Mechanism of Muscle Contraction :



- **Sliding filament theory** - states that contraction of a muscle fibre takes place by the sliding of the thin filaments over the thick filaments.
- Muscle contraction is initiated by a signal sent by the central nervous system (CNS) via a motor neuron.
- A motor neuron along with the muscle fibres connected to it constitute a **motor unit**.
- The junction between a motor neuron and the sarcolemma of the muscle fibre is called the **neuromuscular junction or motor-end plate**.
- A neural signal reaching this junction releases a **neurotransmitter (Acetylcholine)** which generates an action potential in the sarcolemma.

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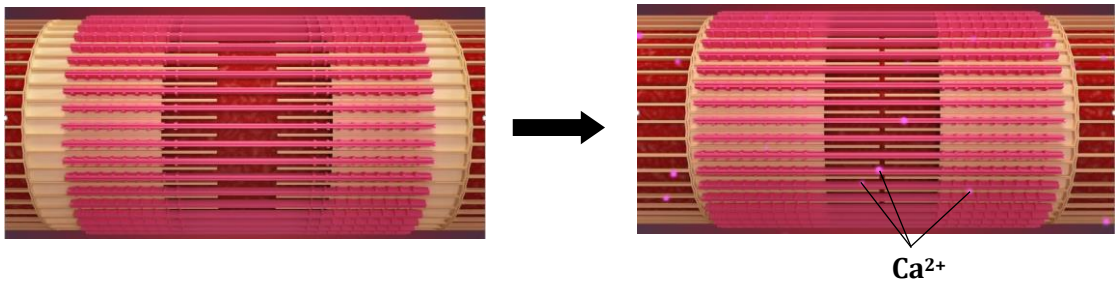
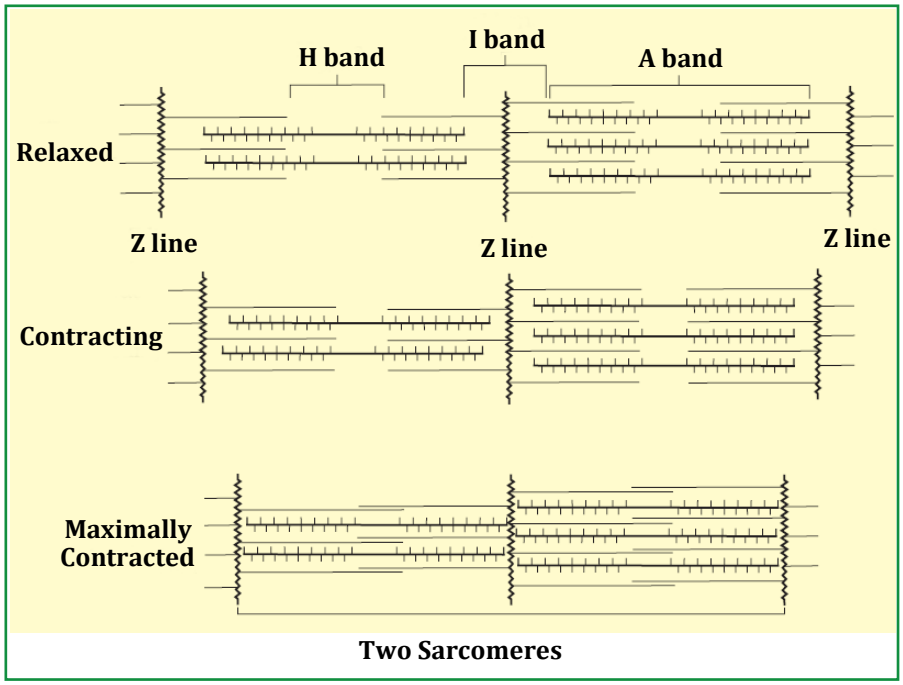
- This spreads through the muscle fibre and causes the release of **calcium ions** into the sarcoplasm.
- This pulls the attached actin filaments towards the centre of 'A' band. The 'Z' line attached to these actins are also pulled inwards thereby causing a shortening of the sarcomere, i.e., contraction.
- During shortening of the muscle (contraction), the 'I' bands get reduced, whereas the 'A' bands retain the length.

Sarcomere in relaxed state → **Sarcomere in contraction state**

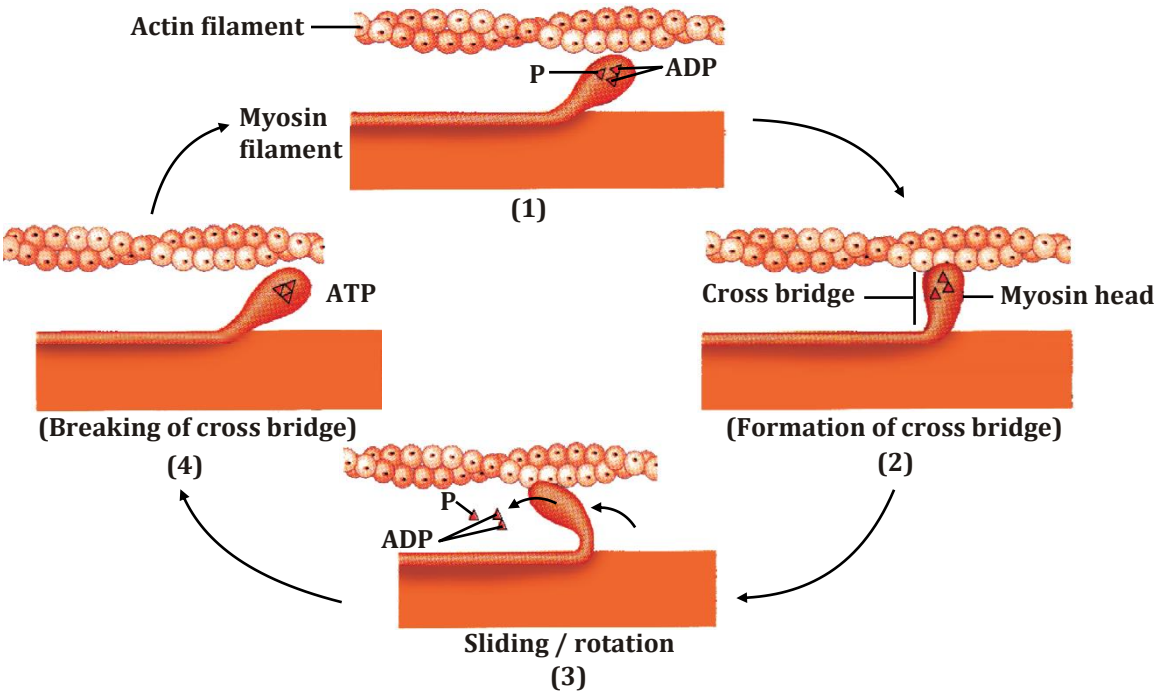




Sliding-filament theory of muscle contraction (movement of the thin Filaments and the relative size of the I band and H zones)

- The binding of **calcium** with a subunit of **troponin** on actin filaments removes **the masking of active sites for myosin**.
- Utilising the energy from ATP hydrolysis, the myosin head now binds to the exposed active sites on actin to form a cross bridge.
- The myosin, releasing the ADP and P_1 goes back to its relaxed state. A new ATP binds and the cross-bridge is broken.
- The ATP is again hydrolysed by the myosin head and the cycle of cross bridge formation and breakage is repeated causing further sliding.

- The process continues till the Ca^{++} ions are pumped back to the sarcoplasmic cisternae resulting in the masking of actin filaments.
- This causes the return of 'Z' lines back to their **original position, i.e., relaxation**.



Stages in cross bridge formation, rotation of head and breaking of cross bridge

(iv) Role of ATP :

(i) The **'back & forth'** movement of myosin head with in the groove.
(ii) **Detachment** of myosin head from the actin.

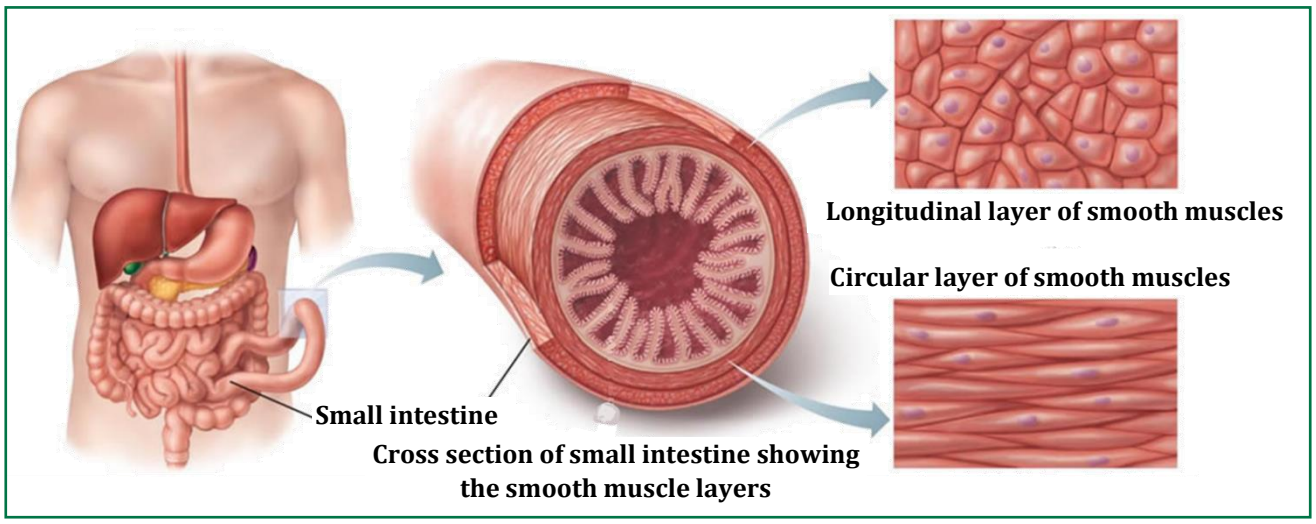
- Repeated activation of the muscles can lead to the accumulation of lactic acid due to anaerobic breakdown of glycogen in them, causing fatigue.

(v) Difference Between Red Muscle and White Muscle :

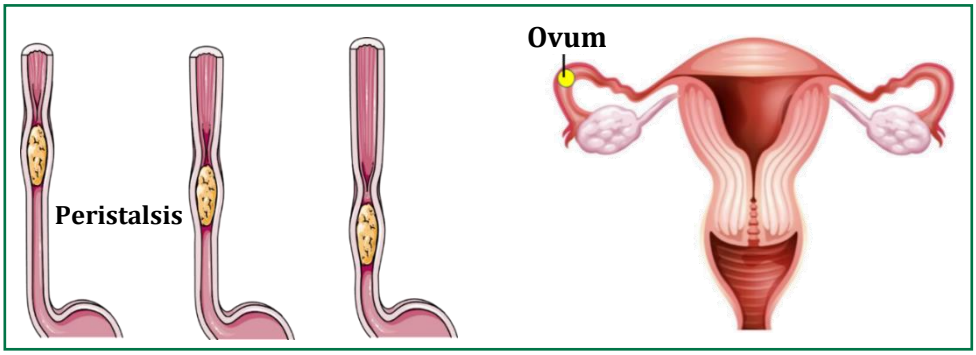
Red (slow) muscle	White (fast) muscle
1. Myoglobin content is high. So, it is red	1. Myoglobin content is less So, it is pale
2. Sarcoplasmic reticulum is less extensive	2. Sarcoplasmic reticulum is more extensive
3. Blood vessels are more extensive	3. Blood vessels are less extensive
4. Mitochondria are more in number	4. Mitochondria are less in number
5. Response is slow with long latent period	5. Response is rapid with short latent period
6. Contraction is less powerful	6. Contraction is more powerful
7. This muscle is involved in prolonged and continued activity as it undergoes sustained contraction	7. This muscle is not involved in prolonged and continued activity as it relaxes immediately
8. Fatigue occurs slowly	8. Fatigue occur quickly
9. Depends on cellular respiration for ATP production so also called aerobic	9. Depends on anaerobic process for energy.

(B) Visceral Muscles :

- Visceral muscles are located in the inner walls of hollow visceral organs of the body like the alimentary canal, reproductive tract, etc.


Longitudinal layer of smooth muscles
Circular layer of smooth muscles
Small intestine
Cross section of small intestine showing the smooth muscle layers

- They do not exhibit any striation and are smooth in appearance. Hence, they are called smooth muscles (nonstriated muscle).
- Their activities are not under the voluntary control of the nervous system and are therefore known as involuntary muscles.
- They assist, for example, in the transportation of food through the digestive tract and gametes through the genital tract.



(C) Cardiac Muscles :

- As the name suggests, Cardiac muscles are the muscles of heart.
- Many cardiac muscle cells assemble in a branching pattern to form a cardiac muscle.
- Based on appearance, cardiac muscles are striated.
- They are involuntary in nature as the nervous system does not control their activities directly.
- It is special type of muscle which found only in heart so it is also called as cardiac muscle. On the basis of structure it is **striated type of muscle**. Intercalated disc, helps in the propagation of impulse & contraction.
- Their muscle fibres are long, cylindrical and branched.
- Many transverse septa are found in the muscle fibre which are called as **intercalated disc**.
- Due to septa fibres are divided into many segments each segment is **uninucleated**. Each segment called individuals cells.

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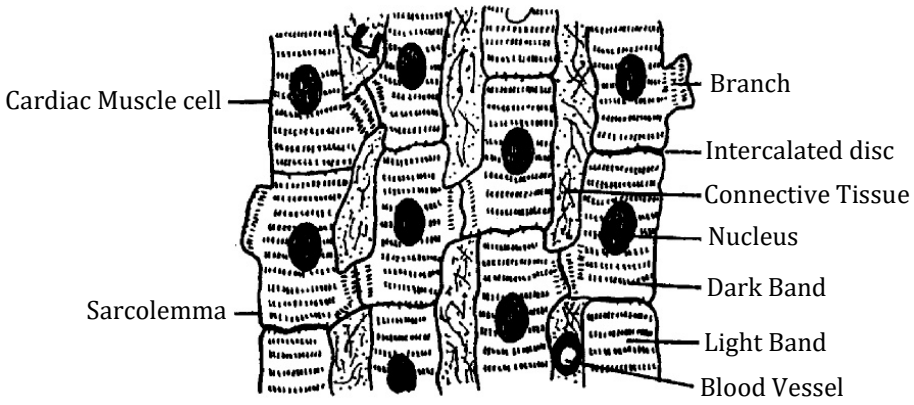
- Dark & light line also found in the Muscle fibre. It is also **non-fatigue type muscle**.
- Its contraction is not controlled by will power of animal.
- On the basis of function it is **smooth muscle type**.



Cardiac muscle fibres

5. Disorders of Muscular System :

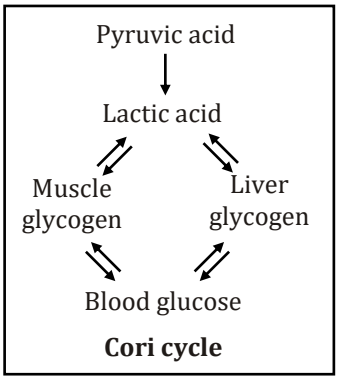
Myasthenia gravis: Auto immune disorder affecting neuromuscular junction leading to fatigue, weakening and paralysis of skeletal muscle.

Muscular dystrophy: Progressive degeneration of skeletal muscle mostly due to genetic disorder.

Tetany: Rapid spasms (wild contractions) in muscle due to low Ca^{++} in body fluid.

★ Golden Key Points ★

1. Muscles make up 40-50% of your total body weight.
2. Humans are born with all the muscle fibres they will ever have.
3. Sartorius **Longest** muscle of body.
4. Stapedius – **Smallest** muscle of body.
5. Jaw muscles (masseter) – are strongest muscle.
6. In Human beings 639 muscle are found. 400 muscles are striated & most of the muscles are found in back region & number of back muscles are 180. Longest smooth muscle is present in uterus of pregnant lady.
7. **Cori cycle –** Lactic acid accumulated in muscles during sustained contraction, formed lactic acid transported in blood as blood lactate to liver where it changes into liver glycogen which is changed in to glucose.



Cori cycle

BEGINNER'S BOX-2 MUSCLE CONTRACTION & DISORDERS

1. Length of following does not decrease during muscle contraction –
(1) Sarcomere (2) A-band (3) I band (4) H-zone

2. Cross bridge is broken due to –
(1) Binding of ATP at myosin head (2) Hydrolysis of ATP at myosin head
(3) Binding of ATP at troponin (4) Hydrolysis of ATP at troponin

3. Multinucleated muscle is –
(1) Skeletal (2) Cardiac (3) Smooth (4) Both (2) & (3)

4. Autoimmune disorder affecting muscle is :
(1) Myasthenia gravis (2) Tetany
(3) Muscular dystrophy (4) Rheumatoid arthritis

5. Organ involved in cori cycle is –
(1) Kidney (2) Spleen (3) Lungs (4) Liver

6. Which one is incorrect for Red-muscle?
(1) Myoglobin content is high. (2) Sarcoplasmic reticulum is less extensive.
(3) Blood vessels are more extensive. (4) Mitochondria are less in number.

7. Which one is correct for White-muscle?
(1) Fatigue occur quickly.
(2) Response is slow with long latent period.
(3) Contraction is less powerful.
(4) This muscle is involved in prolonged and continued activity as it undergoes sustained contraction.

8. Increase in Ca^{++} level leads to the binding of calcium with a subunit of troponin on-
(1) actin filaments (2) myosin filaments
(3) Both (1) and (2) (4) Tropomyosin filaments

9. Cross bridge forms between-
(1) one actin and two myosin filaments. (2) one actin and one myosin filaments.
(3) muscle and nerve cells. (4) two actin and one myosin filaments.

10. Motor-end plate is the junction between-
(1) actin and myosin filaments.
(2) two actin filaments.
(3) sensory neuron and the sarcolemma of the muscle fibre.
(4) motor neuron and the sarcolemma of the muscle fibre.

BEGINNER'S BOX ANSWERS KEY

BEGINNER'S BOX-1	Que.	1	2	3	4	5	6	7	8	9	10
	Ans.	1	3	2	3	2	4	3	1	1	1
	Que.	11	12	13	14	15					
	Ans.	2	1	2	2	4					

BEGINNER'S BOX-2	Que.	1	2	3	4	5	6	7	8	9	10
	Ans.	2	1	4	1	4	4	1	1	2	4

ESSENCE

TYPES OF MOVEMENT

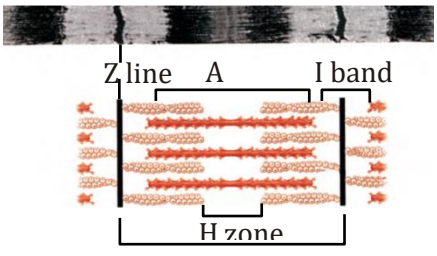
- Amoeboid — e.g. Leucocytes in blood
- Ciliary — e.g. Cilia in trachea
- Muscular — e.g. Locomotion in Human

DIFFERENCE BETWEEN STRIATED, NON-STRIATED AND CARDIAC MUSCLE

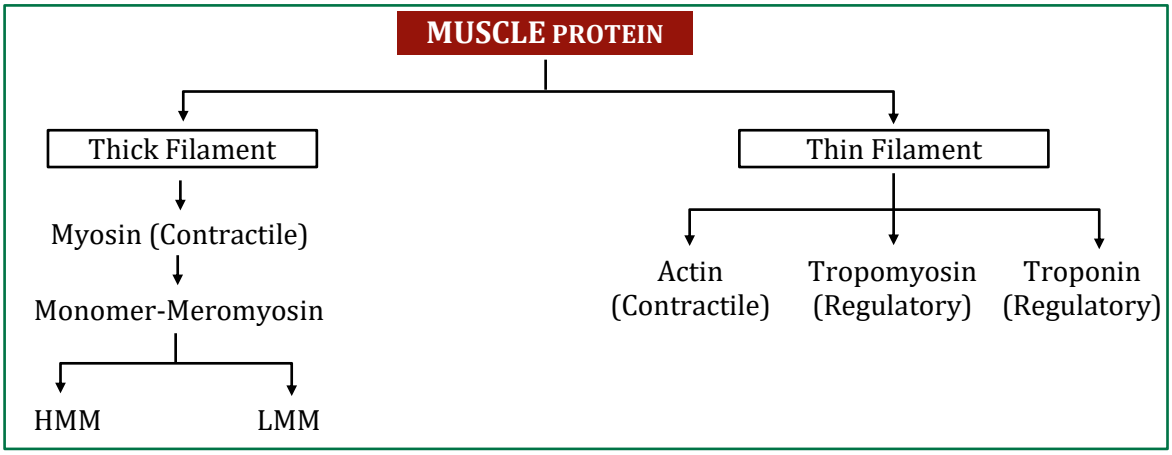
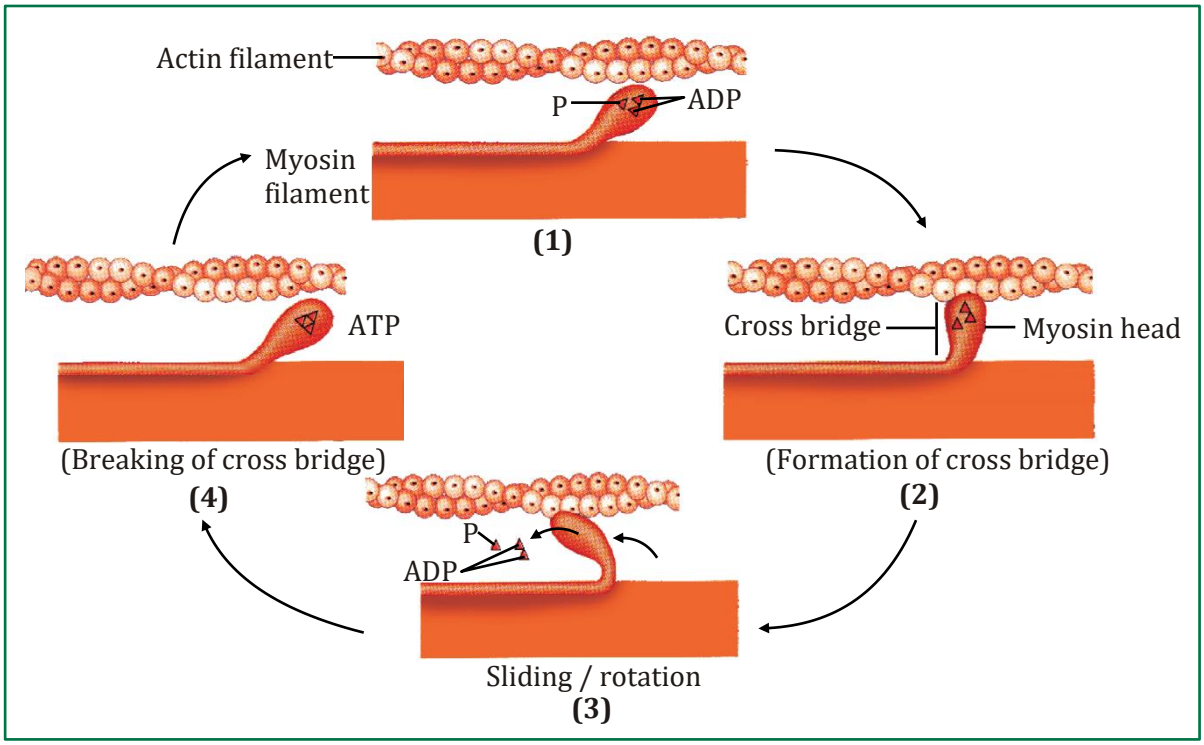
	Striated	Non striated	Cardiac
1.	They are present in upper limb & lower limb etc.	Iris of eye (Ciliary muscle of eye) Urinary bladder, Urinogenital tract, Dermis of skin – Erector pill muscle of dermis	They are present in walls of Heart
2.	Cylindrical	Spindle in shaped	Cylindrical
3.	Fibres Unbranched	Unbranched	Fibres are branched
4.	Multi Nucleated fibres	Uninucleated	Uninucleated
5.	Light and Dark band present	Absent	Present
6.	Controlled by CNS.	ANS	Both CNS + ANS
7.	Soon fatigue.	Do not get fatigue	Never fatigued

SKELETAL MUSCLE

- Structural Unit
  - Muscle fibre — Plasma membrane-sarcolemma
  - Covered by endomysium
  - Bundle of muscle fibres (fascicle)
  - Covered by perimysium
  - Entire muscle covered by epimysium
- Functional Unit
  - Sarcomere
  - 1/2 I + A + 1/2I



Sarcomer



SLIDING FILAMENT THEORY